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SSAA Collaborations in Nuclear Science at LLNL

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NNSA's Stewardship Science Academic Alliances Program (SSAA) has had a tremendous impact on the low-energy nuclear science program at LLNL. Numerous young researchers have been trained through collaborations with US institutions; Texas A&M University and Cyclotron Institute, Rutgers University, University of Richmond, Ohio University, Triangle Universities Nuclear Laboratory in North Carolina, and the University of Tennessee, as well as groups from the United Kingdom, France, Japan, and Canada. A small group of the over 65 active scientists, postdocs, graduate students, and undergraduate students involved in the research program with LLNL is shown in Figure 1.

The activities of the LLNL-related collaborations address important basic science questions such as "How are the elements produced?" and "How do nuclei interact in very neutron-rich environments?" using techniques that also have an impact on practical applications. The SSAA program has created outstanding opportunities for research in a subject area that is both very attractive to students and relevant to the NNSA missions.

The precise determination of nuclear cross sections, which govern the rate at which nuclear reactions take place, is crucial for both NNSA programs and for answering the above questions. Many reactions of interest are very challenging to determine, as they involve short-lived radioactive nuclei that are difficult or impossible to make into targets (Figure 2). At LLNL, we enhance and refine existing techniques to measure cross sections, develop indirect approaches for determining cross sections of short-lived nuclei, and develop predictive theories that describe nuclear reactions and the fission process.

A major research focus has been the development of the surrogate reaction technique [1], which allows us to determine cross sections indirectly via a combination of experiment and theory. A key facility for the experimental effort has been, and continues to be, the STARLiTe detector array currently stationed at Texas A&M Cyclotron Institute. After installing the array at the newly-refurbished K150 Cyclotron earlier this year, the STARLiTe Collaboration has taken data to determine five new cross sections in FY12.

Cross section calculations require reliable nuclear structure data as input. We employ multiple techniques including gamma ray spectroscopy to determine the structure of nuclei, determine half-lives of nuclear states, and study the density of excited states in nuclei.

Nuclear theory developments are indispensable for planning and interpreting the experiments, and for carrying out calculations where measurements are not feasible. Theory is required for describing the surrogate reaction technique and other indirect methods and for extending their applicability for use at existing and future radioactive beam facilities. A predictive theory of the highly complex fission process is an important long-term goal of clear relevance to NNSA that requires a tremendous amount of high-performance computing. Our theory activities have significantly benefited from leverage by other DOE-sponsored research efforts, e.g. the SciDAC-II UNEDF [2,3] and the Topical Collaboration TORUS [4] programs.

The partnership with the SSAA Program has greatly enhanced the interaction between scientists at LLNL and at other institutions. It has produced newly-trained researchers, some of whom have already been hired at national laboratories. The program has also directly enhanced the research carried out by LLNL scientists, as is evident from the large number of related publications (>50 in the past 6 years) in peer-reviewed journals, and numerous presentations at national and international conferences. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

References:
1) J.E. Escher *et al*., Reviews of Modern Physics **84**, 054619 (2012)
2) W. Nazarewicz *et al*., Stockpile Stewardship Quarterly **2**, 6 (2012)
3) R. Furnstahl, Nuclear Physics News **21**, 18 (2011) and http://www.unedf.org/
4) Topical Collaboration TORUS, http://www.reactiontheory.org/

Figure 1. A subset of the STARLiTE Collaboration at the Texas A&M Cyclotron Institute. Back row left to right: Brett Manning (Rutgers), Tim Ross, Richard Hughes, Professor Cornelius Beausang (Richmond), Peter Humby (Yale), Callum Shand (Surrey), William Peters, Andrew Ratkiewicz, Jason Burke (LLNL) and Matt McCleskey (TAMU). Front row: left to right Erin Good, Kristen Gell (Richmond), Samantha Rice (Rutgers), Professor Roby Austin (St. Mary's), and Professor Jolie Cizewski (Rutgers).

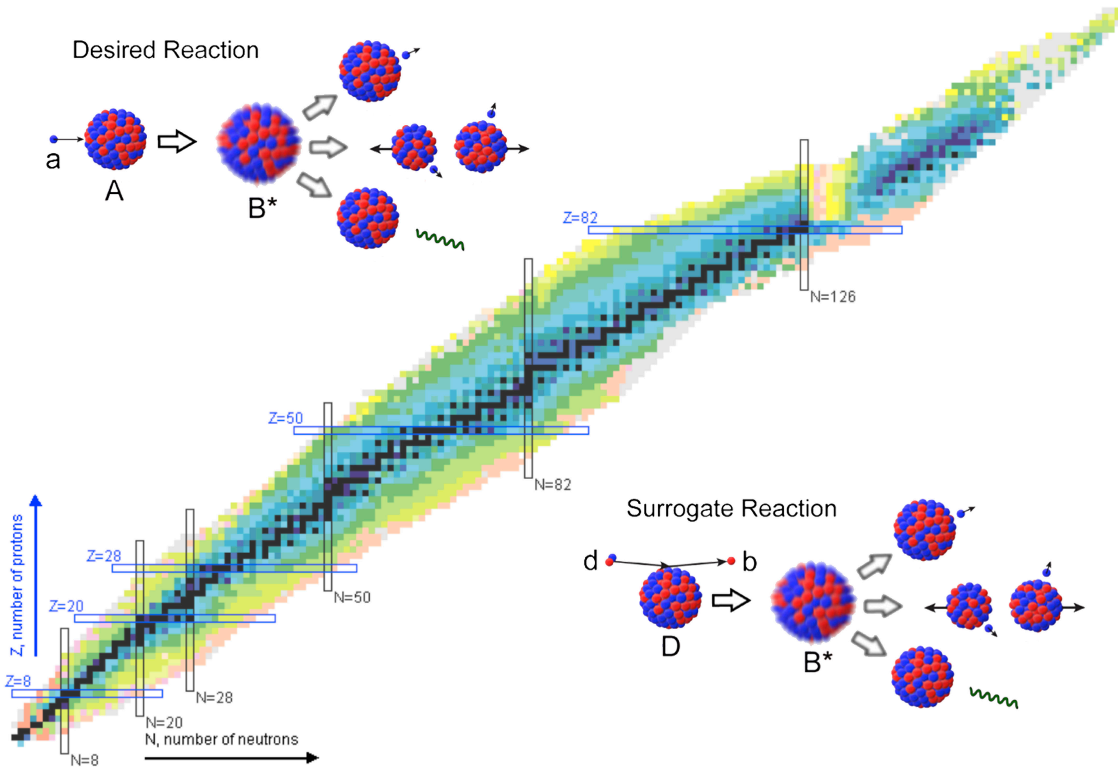

Figure 2. The chart of the nuclides above shows isotopes color-coded by half-life. For the stable isotopes, shown in black, direct neutron-induced reactions are typically used to determine cross sections of interest. However, for most radioactive nuclei (decreasing isotope half-lives are shown in colors from blue through pink), direct measurements are not possible so indirect methods such as the surrogate reaction technique must be used. In the surrogate reaction technique, the same excited nucleus created by neutron capture (the "desired reaction" shown in the upper left) is produced and studied using a different reaction (the "surrogate reaction" shown in the lower right) that is experimentally accessible. The radioactive isotopes near stability can be studied at accelerator facilities today and many additional exotic radioactive isotopes will be readily available at the Facility for Rare Isotope Beams (FRIB) currently under construction.